

1                    MOLTEN METAL PUMP IMPELLER

2            This application is a continuation-in-part of U.S.  
3    Serial No. 10/272,221, filed October 16, 2002, which  
4    application is a division of U.S. Serial No. 09/865,772,  
5    filed May 25, 2001, which application claims priority of  
6    U.S. Provisional Application No. 60/207,554, filed May 27,  
7    2000.

8                    BACKGROUND OF THE INVENTION AND RELATED ART

9            The present invention relates to pumps, and more  
10   particularly to pump apparatus and methods for pumping  
11   molten metal.

12           The use of pumps to pump molten metal such as aluminum  
13   or zinc is known in the art. Generally, molten metal pumps  
14   comprise centrifugal pumps modified to provide processing of  
15   the molten metal. To that end, circulation pumps are used  
16   to equalize temperature and improve homogeneity of mixture  
17   in a molten metal bath, transfer pumps are used to convey or  
18   transfer molten metal between locations and gas-injection  
19   pumps are used to circulate and inject gas into a molten  
20   metal to modify its composition as by removing dissolved  
21   gases or dissolved contaminant metals therefrom.

22           The pumps typically include a base or casing having a  
23   pumping chamber and an impeller received within the chamber.  
24   The base includes inlet and outlet passages for intake and  
25   discharge of the molten metal being pumped. The pump may be  
26   a volute pump wherein the pumping chamber has a volute shape  
27   comprising a spiral configuration of circumferentially  
28   increasing cross sectional area approaching the pump outlet

1 passage. It is also possible to provide the pump with a  
2 pumping chamber having a generally circular shape.

3 The pump base together with the impeller are submerged  
4 in the molten metal and connected via a plurality of support  
5 posts to a drive arrangement positioned above the level of  
6 the molten metal. The impeller is supported for rotation  
7 within the pumping chamber by a rotatable shaft coupled to  
8 the drive arrangement. In typical installations, the drive  
9 shaft may be of various lengths, e.g. one to four feet in  
10 length or longer, in order to provide adequate clearance  
11 above the molten metal level.

12 A typical impeller includes at least two axially  
13 extending vanes and a radially extending member which forms  
14 a base when located below the vanes. In this manner the  
15 impeller provides a vane array with adjacent vanes  
16 cooperating with the base to form vane pockets. During  
17 pumping, molten metal is axially introduced into the pockets  
18 and laterally ejected due to centrifugal force.

19 The necessary spacing between the driver and impeller  
20 results in the use of an elongate drive shaft fixed to the  
21 impeller. This requires a relatively high degree of balance  
22 during operation and adequate bearing support between the  
23 impeller/shaft assembly and the housing. Operating  
24 vibration may damage the pump and/or limit its pumping  
25 efficiency.

26 The impeller may be fractured or otherwise damaged due  
27 to the vibrations and failure to maintain operating  
28 clearances. In molten metal pumping systems, bearings may  
29 be considered to operate on films of molten metal and poor  
30 concentricity yields reduced clearances which may cause the

1 films to break down or not form so as to give rise to  
2 refractory material wear of increased rate.

3 SUMMARY OF INVENTION

4 The pumps and methods are characterized by unique fluid  
5 flow properties tending to smooth the rotation of the  
6 impeller by better equalizing the pressure between each pair  
7 of vanes within the vane array. This tends to reduce pump  
8 damage and bearing wear by suppressing repeated vibrational  
9 impacts during pump operation, e.g., chatter, while  
10 providing improved pump performance.

11 These improvements are achieved in part by the  
12 provision of circumferential feed flows of molten metal to  
13 the interior regions of the impeller during pumping. The  
14 circumferential flows are provided through openings  
15 extending through the vanes. The circumferential flows  
16 tend to enhance the completeness and uniformity of the  
17 filling and evacuation of the vane pocket between each pair  
18 of vanes by accelerating a flow of metal into a lower region  
19 of the pocket.

20 The advantages of circumferential feeds to the vane  
21 pockets or interior regions of the vane array of the  
22 impeller appear to relate to the rapid input of metal to the  
23 vanes pockets following the pumping radial ejection of metal  
24 therefrom. As the impeller begins its uniform circulatory  
25 motion, the continuity of the filling and emptying of the  
26 vane pockets with molten metal is enhanced by the  
27 circumferential flows through the vanes in accordance with  
28 the invention. The quicker one can get the media or molten

1 metal to occupy that empty space the quicker the media will  
2 pump.

3 The fluid flow properties are further enhanced by the  
4 improved balancing or equalization of pressure within the  
5 vane pockets which are believed to reduce vibrations and  
6 fluid flow irregularities during pumping. In turn, the  
7 smoothness of impeller rotation tends to be enhanced by the  
8 increased continuity of the pumping action.

9 The openings extend from the opposed surfaces of the  
10 vane. The openings may be disposed at any location  
11 extending through the circumferential or peripheral  
12 thickness of the vanes and may have any desired axial or  
13 radial orientation. Thus, the openings may be inclined  
14 upwardly or downwardly relative to the direction of impeller  
15 rotation or in an orientation generally parallel with the  
16 impeller base.

17 The fluid or molten metal flow through the opening in  
18 the vane of the impeller is enhanced by disposing the  
19 opening at an inclined angle. That is, the opening is  
20 inclined upwardly into the direction of rotation of the vane  
21 so that an intake vector force is imposed on the fluid to  
22 bias flow into the opening and the interior region of the  
23 impeller. The angular orientation of the opening imposes an  
24 intake vector force on the molten metal that operates to  
25 expedite metal flow into and through the opening.

26 At least one opening may be provided in at least one  
27 vane. More preferably, a single opening may be provided in  
28 each vane or in less than all vanes provided a majority of  
29 the vanes include at least one opening. Accordingly, the  
30 impeller may include an imperforate vane.

1 Multiple openings may be provided in one or more of the  
2 vanes. Thus, an impeller may include imperforate, single  
3 opening and multiple opening vane or vanes. The rotational  
4 balance of the impeller and/or suppression of chatter  
5 characterized by repeated or regular vibrations may be  
6 reduced by trial and error depending upon the interaction of  
7 the impeller configuration, radial member or pump base and  
8 bearing mounting system.

9 The opening may have any convenient cross-sectional  
10 shape. For example, a circular cross-section is convenient,  
11 but oval or other shapes may be used. Further, the shape  
12 and/or size of the cross-sectional opening may vary along  
13 the axial length of the opening. For example, an opening  
14 may be provided with an enlarged inlet to enhance fluid  
15 intake.

16 In a further aspect of the invention, at least one  
17 drain hole provides safe drainage of molten metal from the  
18 impeller during removal of the pump from the molten metal  
19 for service or the like. The drain hole may extend through  
20 the radial member or base of the pump and be located in one  
21 of the vane pockets.

22 The single drain hole also tends to prevent thermal  
23 shock as the pump, or more particularly the impeller, is  
24 submerged into the molten metal. Following service of the  
25 pump apparatus, the impeller is relatively cool. As the  
26 impeller is submerged into the molten metal, the lower  
27 extremities of the impeller or impeller base are rapidly  
28 heated. Such rapid heating from a single side of the  
29 impeller raises the possibility of thermal shock and  
30 fracture of the refractory cement mounting the bearing ring

1 to the impeller base. Accordingly, the rapid flow of the  
2 molten metal through the drain hole to upper impeller  
3 locations or top surface of the base tends to uniformly heat  
4 spaced regions on the impeller so as to suppress the  
5 possibility of thermal shock and fracture of the refractory  
6 cement.

7 Impeller drainage may be further improved by connecting  
8 the vane pocket in which the drain hole is located to other  
9 vane pockets by openings extending through the vanes. In  
10 such an arrangement, the advantages of circumferential flow  
11 and pressure equalization of the vane pockets are also  
12 achieved.

13 The selective angular placement of the drain opening or  
14 hole also serves to better balance the impeller. For  
15 example, the impeller may be characterized by material,  
16 configuration or dimensional variations which detract from  
17 true or balanced rotation without vibration. These  
18 variations may be offset by placement of the drain opening  
19 adjacent a location of increased angular momentum or higher  
20 rotational weight or the like that tends to detract from  
21 smooth rotation.

22 In accordance with yet another aspect of the invention,  
23 one or more additional hub drain holes may be provided.  
24 Such hub drain holes comprise openings extending through the  
25 impeller hub or other structure located just above the  
26 impeller radial member or base and communicating with the  
27 impeller drive shaft opening. As indicated, such hub drain  
28 holes are positioned just above the impeller radial member  
29 or base in order to enhance complete drainage of the vane  
30 pockets.

1        In accordance with a further aspect of the invention,  
2        an improved impeller includes a body having a longitudinal  
3        axis and a plurality of elongate pumping chambers located  
4        adjacent the peripheral extremities of the body. The  
5        impeller body includes an end surface and a peripheral  
6        surface. The pumping chambers comprise elongate cavities or  
7        bores that intersect the end surface of the body to form  
8        cooperating impeller inlet openings and the peripheral  
9        surface of the body to form cooperating impeller outlet  
10       openings.

11       The pumping chambers have a length and a transverse  
12       width. The length to width ratio is 3:1 or greater, and  
13       more preferably, is in the range of from about 3:1 to about  
14       20:1, and more preferably, from about 3:1 to about 5:1. As  
15       explained in greater detail, the chamber length to width  
16       ratio may be further decreased to 1:1 or less, with a  
17       reduction of maximum pumping pressure but increased chamber  
18       clearances to pass debris without damaging the pump.

19       In illustrated embodiments, the impeller body has a  
20       cylindrical shape and each pumping chamber has a length that  
21       extends in a linear direction along the peripheral or  
22       cylindrical surface of the body. The pumping chambers  
23       extend along 10 to 100% of the longitudinal dimension of the  
24       body, or more preferably from 20% to 85%.

25       The pumping chamber may be disposed at an angle with  
26       respect to the longitudinal axis of the body ranging from 0°  
27       to 45°. The pumping chambers are inclined into the  
28       direction of impeller rotation and provide multiple flow  
29       pumping forces. More particularly, the inclined pumping  
30       chambers provide axial pumping by applying an axial force

1 vector to the fluid as well as radial pumping by applying  
2 centrifugal force to the fluid in the chamber. Such  
3 multifold pumping yields increased pressure and flow as  
4 compared with similarly sized impellers not having axial  
5 pumping.

6 As indicated, the pumping chambers are located adjacent  
7 the radial extremities of the body. Preferably, the pumping  
8 chambers are located in the outermost 1/3 of the transverse  
9 or radial dimension of the body.

10 BRIEF DESCRIPTION OF THE DRAWINGS

11 Fig. 1 is a side view, partly in section, of a molten  
12 metal pump having an impeller in accordance with the  
13 invention;

14 Fig. 2 is a perspective view on an enlarged scale of  
15 the impeller from the pump of Fig. 1;

16 Fig. 3 is a fragmentary sectional view, on an enlarged  
17 scale, taken along the line 3-3 in Fig. 2;

18 Fig. 4 is a fragmentary sectional view similar to Fig.  
19 3 of a pump vane in accordance with another embodiment of  
20 the invention;

21 Fig. 5 is a top plan view of an impeller in accordance  
22 with yet another embodiment of the invention;

23 Fig. 6 is a top plan view similar to Fig. 5 of an  
24 impeller in accordance with a further embodiment of the  
25 invention;

26 Fig. 7 is an elevational view, partly in section, taken  
27 along the line 7-7 Fig. 6;



1        Fig. 8 is a top plan view similar to Fig. 6 of an  
2        impeller in accordance with yet a further embodiment of the  
3        invention;

4        Fig. 9 is an elevational view, partly in section, taken  
5        along the line 9-9 in Fig. 8;

6        Fig. 10 is a top plan view similar to Fig. 8 of an  
7        impeller having pumping chambers in accordance with another  
8        embodiment of the invention;

9        Fig. 11 is a side elevational view of the impeller of  
10       Fig. 10;

11       Fig. 11A is a graph showing the relative maximum  
12       pumping pressure for various impellers;

13       Fig. 12 is a top plan view similar to Fig. 10 of an  
14       impeller in accordance with yet another embodiment of the  
15       invention;

16       Fig. 13 is a side elevational view of the impeller of  
17       Fig. 12;

18       Fig. 14 is a top plan view, partly in section, of an  
19       impeller in accordance with another embodiment of the  
20       invention;

21       Fig. 15 is a side elevational view of the impeller of  
22       Fig. 14;

23       Fig. 16 is a fragmentary sectional view similar to Fig.  
24       7 showing a further embodiment of the invention; and

25       Fig 17 is a fragmentary sectional view similar to Fig.  
26       16 showing another embodiment of the invention.

27       DETAILED DESCRIPTION OF THE INVENTION.

28       Referring to Fig. 1, a molten metal pump 10 includes a  
29       casing or base member 12 having an impeller 14 mounted

1     therein. The impeller 14 is secured to a shaft 16 and  
2     mounted for rotation within the base member 12. The shaft  
3     16 may be formed of a refractory material such as graphite  
4     and provided with a protective coating of a refractory  
5     material such as silicon carbide or boron nitride. The  
6     upper end of the shaft 16 is connected via a coupling 17  
7     with an upper shaft 18 to a motor 20. The motor 20 may be  
8     of any desired type and, for example, may be air or electric  
9     driven.

10       The pump 10 includes support posts 22 and 24. The  
11     posts are provided with protective sleeves 26 also formed of  
12     a refractory material, for example, as is known in the art.  
13     The post 22, 24 are connected to a support plate 28. In a  
14     known manner, the motor 20 is mounted to a motor support  
15     platform 30 by means of struts 32. The lower ends of the  
16     posts 22 and 24 are attached to the base 12 by means of a  
17     refractory cement and/or mechanical fasteners.

18       The pump 10 is a circulation pump and includes a pump  
19     outlet passage 34 from which the metal is discharged for  
20     circulation within a vessel (not shown). A riser (not  
21     shown) may be connected to the outlet passage 34 to form a  
22     transfer pump. Gas may be injected into the passage 34 to  
23     provide a gas injection pump.

24       The pump 10 has a top feed orientation, and molten  
25     metal access is provided through an opening 35 in the upper  
26     regions of the base 12. For convenience, a generally open  
27     configuration is shown, even though preliminary debris  
28     screening arrangements may be provided. The impeller 14 may  
29     be secured to the shaft 16 by means of a threaded

1 connection, cement and/or mechanical interference members  
2 such as pins.

3 A lower impeller bearing 38 engages a lower base  
4 bearings 42. The bearings comprise ring members of silicon  
5 carbide adhesively mounted within bearing support grooves by  
6 a refractory cement.

7 Referring to Figs. 2 and 3, the impeller 14 includes a  
8 radially extending member or base 44, angularly spaced vanes  
9 46 and a central hub 48 having a shaft receiving opening 49.  
10 The vanes 46 extend radially from the hub 48 and project  
11 axially from an upper surface 50 of the base 44 to  
12 cooperatively form a vane array 46a that has a generally  
13 cylindrical outline defined by the extremities of the vanes  
14 46. The upper terminal extremities of the vanes 46  
15 collectively define an impeller upper inlet 52.

16 As best shown in Fig. 1, a wear ring 53 is positioned  
17 around the upper housing opening 35. The ring 53 is formed  
18 of a refractory material and provides radial and axial wear  
19 surfaces of increased hardness about the opening 35 for  
20 receipt of molten metal passing through the opening and into  
21 the impeller upper inlet 52.

22 In the illustrated embodiment, the upper inlet 52 is  
23 formed by openings 54 radially extending between adjacent  
24 vanes 46. The opening 54 generally extends in a radial plane  
25 between adjacent vanes, and the peripheral boundary for one  
26 of the openings 54 is shown in phantom outline in Fig. 2.  
27 Accordingly, molten metal enters the impeller through upper  
28 inlet 52 via downward flow into each of the openings 54 as  
29 shown by the arrow A.

1       The flow of molten metal entering the impeller 14  
2 through the inlet openings 54 is discharged through an  
3 impeller outlet 60 collectively provided by the axially  
4 extending openings 62 between adjacent vanes 46. The  
5 openings 62 extend in segmented cylindrical planes between  
6 adjacent vanes 46, and the peripheral boundary of one of the  
7 openings 62 is shown in phantom outline in Fig 2.

8       Each of the vanes 46 includes a leading surface 64 and  
9 a trailing surface 66 with respect to the direction of  
10 impeller rotation. The vane has a circumferential thickness  
11 between the surfaces 64 and 66 which may be of uniform  
12 dimension as shown in Fig. 2 or of increased size adjacent  
13 the base 44.

14       Each of the vanes 46 includes an opening 70 extending  
15 through its thickness from an inlet 72 in the surface 64 to  
16 an outlet 74 in the surface 66. As shown in elevation in  
17 Fig. 3, the vane 46 moves right to left during impeller  
18 rotation and the opening 70 is upwardly inclined in the  
19 direction of rotation. In this manner, flow of molten metal  
20 through the hole 70 is directed downwardly into the lower  
21 region of the vane pocket defined between adjacent trailing  
22 and leading surfaces of adjacent vanes.

23       The opening 70 may be inclined at any convenient angle  
24 provided an inlet and outlet are respectively formed in the  
25 leading and trailing surfaces of the vane. Accordingly, the  
26 opening may be inclined upwardly or downwardly relative to  
27 the direction of rotation, and it may be parallel or skewed  
28 relative to a plane passing through the axis of the  
29 impeller.

1       The opening may be of circular cross-section or non-  
2 circular cross-section, e.g., slot-shaped. The diameter of  
3 a circular opening may range up to about 2", or more  
4 preferably, may be in the range of from about 1/8" to 2".

5       The opening 70 is located so that the inlet 72 is  
6 adjacent the impeller inlet 52 and the hub 48. This tends  
7 to promote flow through the opening 70 since a region of  
8 low-pressure exists within the impeller at locations  
9 adjacent the hub 48. That is, the pressure is sufficiently  
10 low to bias intake flow of the molten metal into the  
11 impeller. The fluid pressure within the impeller 14  
12 increases in a radially outward direction. At locations  
13 radially remote of the hub, a positive pressure is developed  
14 so is to tend to favor discharge of molten metal from the  
15 impeller. Accordingly, it is preferable that the inlets 72  
16 of the openings 70 are located in close radial proximity  
17 with the hub 48 in order to enhance the intake flow of  
18 molten metal. The exit can be as shown to use a centrifugal  
19 force vector to enhance flow. The size of the openings 70  
20 and their radial positioning may be selected to achieve the  
21 desired intake flow.

22       Referring to Fig. 4, a modified vane 46' includes a  
23 plurality of openings 70' and 70". As shown, a vane may  
24 include openings of different configurations and  
25 orientations as discussed below.

26       The opening 70' extends in a direction that is  
27 substantially parallel with the plane of the base 44. The  
28 opening 70' includes an enlarged portion 76 providing an  
29 inlet 72' of increased cross-section as compared with the  
30 cross-section of the remaining portion of the opening. The

1 opening 70' terminates at an outlet 74' in the trailing  
2 surface 66.

3 The opening 70" has an inlet 72" in the leading surface  
4 64 and an outlet 74" in the trailing surface 66. As shown,  
5 the opening 70" extends in a direction that is inclined  
6 downwardly in the direction of rotation. Such a downwardly  
7 inclined orientation, may be useful in reducing vibrational  
8 tendencies and/or smoothing impeller rotation.

9 Referring to Fig. 5, an impeller 80 has a radially  
10 extending base 82, a central hub 84 and radially extending  
11 vanes 86. In this arrangement, the vanes 86 are straight  
12 vanes as compared with the curved vanes 46 of the first  
13 embodiment.

14 A pair of openings 88 extend through each of the vanes  
15 86 at radially spaced locations. It is not necessary that  
16 each of the vanes 86 has an identical number of openings  
17 therethrough. For example, it may be preferable in some  
18 arrangements to alternately use single and plural openings  
19 through sequential vanes.

20 Referring to Figs. 6 and 7, an impeller 90 has a  
21 radially extending base 92, a central hub 94 and radially  
22 extending vanes 96. The hub 94 includes a drive shaft  
23 opening 97 and an axis 97a about which the impeller rotates.  
24 Although the vanes 96 are shown to be straight vanes, curved  
25 vanes or other vane configurations may be used.

26 An opening 98 extends through each of the vanes 96.  
27 More particularly, the opening 98 extends from a leading  
28 surface 96a to a trailing surface 96b of each of the vanes.  
29 As shown, the openings 98 have a circular configuration, but  
30 other shapes may be used.

1       The openings 98 provide circumferential flow of molten  
2 metal between the vane pockets and tend to smooth rotation  
3 of the impeller by equalizing the pressure between each pair  
4 of vanes within the vane array as described above.

5       In addition to the openings 98, a single drain hole or  
6 opening 100 extends through the base 92 for purposes of  
7 enhancing the drainage of molten metal from the vane pockets  
8 upon removal of the pump from below the surface of the  
9 molten metal. The opening 100 has a circular cross-section,  
10 but it may have any convenient cross-sectional shape.

11       The opening 100 also has a longitudinal axis 100a.  
12 Preferably, the opening 100 is parallel with the axis of the  
13 impeller 90, or more particularly, the axis 100a of the  
14 opening 100 is parallel with the axis 97a of the opening 97.

15       The impeller 90 includes four vane pockets, each being  
16 defined by the adjacent trailing and leading vane surfaces  
17 together with the intermediate hub and base surface  
18 portions. As the pump is removed from the molten metal,  
19 molten metal will drain through the opening 100 to  
20 substantially empty the associated vane pocket and cause  
21 molten metal in other vane pockets to flow through the  
22 openings 98 into the drained vane pocket associated with the  
23 opening 100. In some instances, the pump may be tipped from  
24 a vertical orientation during its removal to naturally drain  
25 the vane pocket or pockets in the lower-most orientations.  
26 Such tipping of the pump will also result in the flow of  
27 molten metal trapped within the upper-most vane pockets  
28 through the openings 98 to the lower-most vane pocket or  
29 pockets and more complete drainage.

1       The selected axial positioning of the openings 98 also  
2 tends to enhance drainage. Preferably, the openings 98 are  
3 located just above the upper extremities of the base 92. As  
4 shown in Fig. 7, the openings 98 are positioned immediately  
5 above an upper annular shaped surface 92a of the base 92 to  
6 more fully drain the vane pocket.

7       In addition to its drainage functions, the drain  
8 opening 100 also tends to reduce thermal shock when the  
9 impeller is introduced into the molten metal. For example,  
10 following repair or other servicing of the pump, the  
11 temperature of the impeller will be relatively cool as it is  
12 submerged in the molten metal. The rapid heating of lower  
13 surface 92b of the base 92 may thermally shock and fracture  
14 the refractory cement with which the lower base bearing 42'  
15 is mounted. It is believed that the tendency of such  
16 thermal shock and/or fracture to occur is suppressed by the  
17 prompt flow of molten metal through the opening 100 and into  
18 contact with the upper surface 92a of the base 92.  
19 Consequently, the opening 100 has a function independent of  
20 drainage, and it may be the only aperture in the base or  
21 vane arrangement of the impeller.

22       The opening 100 may be selectively placed to further  
23 enhance the balance and vibration-free rotation of the  
24 impeller. Typically, the construction of the impeller 90  
25 may include an angular location of excess momentum or weight  
26 as determined by the stopped orientation of the impeller  
27 following free rotation about a horizontal axis. The  
28 opening 100 may be positioned at such location.

29       Referring to Figs. 8 and 9, an impeller 102 has a  
30 radially extending base 104, a central hub 106 and radially



1 extending vanes 108. A drive shaft opening 110 extends  
2 axially through the hub 106. Drain openings 112 extend  
3 radially through the hub 106 and a drain opening 114 extends  
4 axially through the base 104.

5 As best shown in Fig.8, a drain opening 112 is  
6 associated with each of the vane pockets formed by the  
7 adjacent vane pairs and associated impeller surfaces. Each  
8 drain opening 112 extends between an outlet 112a in the  
9 shaft opening 110 and an inlet 112b in its associated vane  
10 pocket. It should be appreciated that during impeller  
11 rotation, molten metal flow will occur in a radially outward  
12 direction through the openings 110 and the outlet and inlet  
13 roles will be reversed.

14 Referring to Fig. 9, a portion of a drive shaft 16' is  
15 shown in dotted outline. The drive shaft 16' terminates at  
16 a location above the openings 112, or more particularly, the  
17 outlets 112a. The openings 112 extend radially through the  
18 annular wall of the hub 106 at locations just above the base  
19 104, and more particularly, an upper base surface 104a.

20 The drain opening 114 provides accelerated drainage of  
21 its associated vane pocket and also suppression of thermal  
22 shock as described above with respect to the drain opening  
23 100.

24 Referring to Figs. 10 and 11, an impeller 120 in  
25 accordance with a further embodiment of the invention is  
26 shown. The impeller 120 has a monolithic construction of a  
27 refractory material such as graphite. The impeller 120 has  
28 a generally cylindrical body 122 including a central shaft  
29 opening 124 which may be provided with internal threads for  
30 engaging a shaft (not shown). The body 122 has an upper

1 radial surface 126, a cylindrical side surface 128 and a  
2 lower radial surface 130. A lower impeller bearing 132,  
3 similar to the bearing 42 in the first embodiment, is  
4 located adjacent the bottom periphery of the impeller 120  
5 for engagement with a base or housing bearing.

6 The impeller also includes a plurality of the elongate  
7 peripheral pumping chambers 134 that each intersect the  
8 radial surface 126 or extremity of the impeller to form  
9 chamber openings 136. The chambers 134 extend to an axial  
10 terminal end above the base region of the impeller and  
11 spaced from the bearing 132.

12 For convenience, the impeller is shown in a top feed  
13 orientation, and includes an upper impeller inlet 138  
14 collectively formed by radially extending openings 136. An  
15 impeller outlet 140 is provided by openings 142 formed in  
16 the radial extremities of the impeller along the length of  
17 each of the pumping chambers 134.

18 As shown, the chamber 134 has a rectangular cross-  
19 section that is formed by radially cutting the body 122 as  
20 with a radially oriented drill bit moved in an axial or  
21 longitudinal direction along the body surface 128. Each of  
22 the chambers 134 has a chamber length extending along a  
23 longitudinal chamber axis 134a and a transverse axis 134b  
24 extending in a plane that is perpendicular to the  
25 longitudinal axis. The cross-sectional shape of the pumping  
26 chamber 134 is generally rectangular, but it may be  
27 circular, polygonal or irregular.

28 As shown, the chamber length as measured along its  
29 longitudinal axis is substantially greater than the major

1 cross dimension or widths measured along its transverse axis  
2 134b. The ratio of chamber length to width may be 3:1 to  
3 20:1, and more preferably, 3:1 to 5:1. Illustrative sizes  
4 of pump chamber lengths range from 2" to 6" or greater and  
5 pumping chamber widths range from 0.25" to 1.5" or greater.

6 As the ratio of pumping chamber length to width is  
7 further decreased to 1:1 or less, the maximum pumping  
8 pressure is decreased, but the minimum chamber dimension is  
9 increased and the chamber geometry better allows the passage  
10 of solid debris or contaminants through the pump without  
11 pump damage. Accordingly, there is a trade-off between the  
12 maximum pumping pressure and the size of the debris that can  
13 pass through the chamber without damaging the pump.

14 As best shown in FIG. 10, the pumping chambers 134  
15 comprise elongate bores or holes in the body 122 that have  
16 longitudinal surfaces including a radially inner surface  
17 135a extending to a leading surface 134b and a trailing  
18 surface 135c which respectively extend to the openings 142.  
19 The surfaces 135a, 135b and 135c may be planar as shown or  
20 arcuate as well as combinations thereof.

21 The pumping chambers 134 are preferably angularly  
22 spaced about the periphery of the impeller 120 in a uniform  
23 pattern. An even or odd number of pumping chambers may be  
24 used. An odd number of chambers may tend to reduce  
25 vibration during pumping operation.

26 The peripheral location of the pumping chambers is  
27 preferred since the highest impeller surface speeds and  
28 centrifugal force are encountered at the periphery. This  
29 tends to eject any particulate contaminants and reduce the  
30 tendency for blockage to occur. As best shown in Fig. 10,

1 the pumping chambers 134 are located in the radially  
2 outermost 1/3 of the body 122. In contrast, most vane or  
3 blade impellers have vane pockets extending over 40% of the  
4 radial extent of the impeller body.

5 The pumping chambers 134 extend along the surface 128  
6 an axial distance corresponding with about 80% of the  
7 longitudinal extent of the body 122. Generally, the pumping  
8 chambers should extend along at least 10% and may extend  
9 along all of the longitudinal extent of the body.

10 The total number of chambers and the dimensions of the  
11 chambers may be varied in accordance with the desired  
12 pumping flows. Preferably, the pumping chambers are  
13 inclined into the direction of rotation which is clockwise  
14 as shown in FIGS. 10 and 11. As measured from the vertical  
15 or with respect to the longitudinal axis A of the impeller  
16 120, the angle of inclination may range up to 45 degrees.  
17 Herein, the pumping chamber surfaces are similarly inclined,  
18 and the trailing surface 135c provides an axial pumping  
19 force represented by the force vector Fa in FIG. 11. This  
20 axial pumping force enhances fluid flow into and through the  
21 chamber 134, and cooperates with the centrifugal force to  
22 rapidly intake and discharge fluid. In this manner, both  
23 axial and radial pumping are imposed on the fluid within the  
24 chamber 134. In comparison, known commercially available  
25 molten metal pumps rely solely on gravity to provide an  
26 axial feed into the pump.

27 In illustration of multiflow pumping in accordance with  
28 the invention, the maximum pumping pressures of the  
29 following impellers were compared using the same pump drive  
30 arrangement and pump housing in a water system. The

1 impellers were similarly sized and sequentially fitted to  
2 the pump shaft for operation at a constant speed to  
3 determine the maximum pumping pressure. The maximum pumping  
4 pressure was determined by measuring the maximum pressure  
5 developed in a 1 1/2 in. ID closed conduit connected to the  
6 pump outlet.

## Impellers

1. Impeller 120 with a 30 degree pump chamber inclination and eight pumping chambers.
2. An impeller similar to impeller No. 1, but having a pumping chamber length to width ratio less than 3: 1.
3. A standard six hole squirrel cage impeller.
4. An impeller having three curved vanes.
5. An impeller having four flat vanes similar to FIG. 4 in U.S. Patent 5,586,863.
6. An impeller having four flat vanes similar to FIG. 3A in U.S. Patent 5,586,863.
7. An impeller having three straight vanes.
8. A trilobular impeller similar to FIG. 5 in U.S. Patent 5,203,681.
9. An impeller similar to impeller No. 8, but inverted to give bottom feed.
10. An impeller having four curves vanes.
11. An impeller similar to impeller No. 1, but having a cone-shaped upper body.

Referring to FIG. 11A, the maximum pumping pressures for impellers Nos. 1 through 11 are shown: Impeller No. 1, in accordance with the invention, developed a maximum

1 pressure of 5 psi so as to exceed the next highest pressure,  
2 impeller No. 3 at 3 psi, by about 67 percent. Impeller No.  
3 1 also exceeded impeller No. 2 which had a similar  
4 construction, but a pumping chamber length to width ratio of  
5 less than 3:1. Although impeller No. 2 had a lower maximum  
6 pressure, its length to width ratio of less than 3:1  
7 provides greater chamber clearance for passage of debris  
8 without pump damage.

9 Generally, the multiflow impeller of the invention  
10 provided about twice the maximum output pressure of prior  
11 art vane, blade and trilobular impeller designs represented  
12 by impellers Nos. 3 through 10. The increased maximum  
13 pressure provided by the multiflow impeller is proportional  
14 to volume flow and increased pumping efficiency. High  
15 pumping pressures are particularly useful in pumping  
16 relatively dense metals for both circulation and lifting.  
17 For example, high pressure is particularly advantageous in a  
18 zinc system to provide lift heights since the density of  
19 zinc is about 449 lbs./ft<sup>3</sup> compared with 170 lbs./ft<sup>3</sup> for  
20 aluminum and 62 lbs./ft<sup>3</sup> for water.

21 As shown in Figs. 10 and 11, the pumping chambers 134  
22 may be connected by openings 144 extending therebetween.  
23 The openings 144 provide circumferential flow and the  
24 advantages as described above.

25 Referring to Figs. 12 and 13, an impeller 150 is shown.  
26 The impeller 150 is substantially identical with the  
27 impeller 120, and for convenience, corresponding elements  
28 are similarly numbered with the addition of a prime  
29 designation.

1       The pumping chambers 134' of the impeller 150 are  
2 connected by openings 144' and provide advantages  
3 corresponding with those discussed above. The openings 144'  
4 are axially located adjacent the lower extremities or  
5 bottoms 152 of the chambers 134' to also enhance drainage.  
6 To that end, a drain opening 154 has an inlet 154a in the  
7 bottom 152 of the chamber 134' and an outlet 154b in the  
8 lower radial surface 130' of the impeller 150.

9       The openings 144' provide circumferential flows and the  
10 advantages discussed above. Similarly, the openings 144'  
11 cooperate with the drain opening 154 to provide similar  
12 drainage advantages. The opening 154 also tends to suppress  
13 thermal shock.

14       Referring to Figs. 14 and 15, an impeller 160 is shown.  
15 The impeller 160 is substantially identical with the  
16 impellers 120 and 150, and for convenience, corresponding  
17 elements are similarly numbered with the addition of a  
18 double prime designation.

19       The pumping chambers 134" each include a radial drain  
20 opening 162. The openings 162 are located adjacent the  
21 lower extremities or bottoms 152" of the pumping chambers  
22 134". Accordingly, the opening 162 includes an inlet 162a  
23 in or adjacent to the bottom 152" and an outlet 162b in the  
24 shaft opening 124". The openings 162 extend above the base  
25 region of the impeller 160 and the outlets 162b are located  
26 in the shaft opening 124" remote of a received shaft. In  
27 the impeller 160, individual drainage of each of the pumping  
28 chambers 134" is provided through its associated opening  
29 162.

1       The drain opening 164 extends axially to the lower  
2 radial surface 130". Thus, the opening 164 has an inlet  
3 164a in the bottom 152" and an outlet 164b in the lower  
4 radial surface 130". The opening 164 is believed to achieve  
5 the same drainage and thermal shock advantages as described  
6 above with respect to the opening 154.

7       Referring to Fig. 16, an impeller 170 is shown. The  
8 impeller 170 is similar to the impeller 14 and includes a  
9 radially extending member or base 172, a central hub 174 and  
10 radially extending vanes 176. The hub 174 includes a drive  
11 shaft opening 178 and a drive shaft 180 engaged therein is  
12 shown.

13       The impeller 170 includes one or more openings or drain  
14 holes 182 extending from an inlet 182a in an upper surface  
15 172a of the base 172 to an outlet 182b in a cylindrical wall  
16 178a forming the drive shaft opening 178. The opening 182  
17 has a cylindrical configuration and circular cross-section,  
18 but any convenient shape may be used. The openings 182  
19 provide the same advantages as discussed above with respect  
20 to the opening 100. It should be appreciated that the inlet  
21 opening 182a may extend across the intersection between the  
22 hub 174 and base 172. In this case, the opening 182a  
23 extends in both a cylindrical surface 174a of the hub 174  
24 and the upper surface 172a of the base 172.

25       During operation, the opening 182 also pumps fluid  
26 radially outward therethrough to provide increased flow.  
27 This additional pumping provides a jet flow of fluid to  
28 dislodge accumulated debris. The opening 112 in Fig. 9  
29 provides a similar function.



1        Referring to Fig. 17, an impeller 190 is shown. The  
2        impeller 190 is similar to the impeller 120 and has a  
3        generally cylindrical body 192 including a central shaft  
4        opening 194. A drive shaft 195 is shown engaged within the  
5        drive shaft opening 194. The body 192 has an upper radial  
6        surface 196, a cylindrical side surface 198 and a lower  
7        radial surface 200. The impeller 190 also includes a  
8        plurality of peripheral pumping chambers 202.

9        The pumping chamber 202 has a bottom 204. A drain  
10       opening 206 has an inlet 206a in the bottom 204 of the  
11       pumping chamber and an outlet 206b in the shaft opening 194,  
12       or more particularly, a cylindrical wall 194a thereof. The  
13       opening 206 tends to provide the drain and thermal shock  
14       suppression advantages as discussed above with respect to  
15       the opening 154. During operation, the opening 206 provides  
16       a jet flow of fluid to dislodge debris in a manner similar  
17       to that described above with respect to opening 112 in Fig.  
18       9 and opening 182 in Fig. 16.

19       While the invention has been shown and described with  
20       respect to particular embodiments thereof, this is for the  
21       purpose of illustration rather than limitation, and other  
22       variations and modifications of the specific embodiments  
23       herein shown and described will be apparent to those skilled  
24       in the art all within the intended spirit and scope of the  
25       invention. Accordingly, the patent is not to be limited in  
26       scope and effect to the specific embodiments herein shown  
27       and described nor in any other way that is inconsistent with  
28       the extent to which the progress in the art has been  
29       advanced by the invention.